

Soil drainage effects on burn severity and landscape level carbon storage in boreal forests

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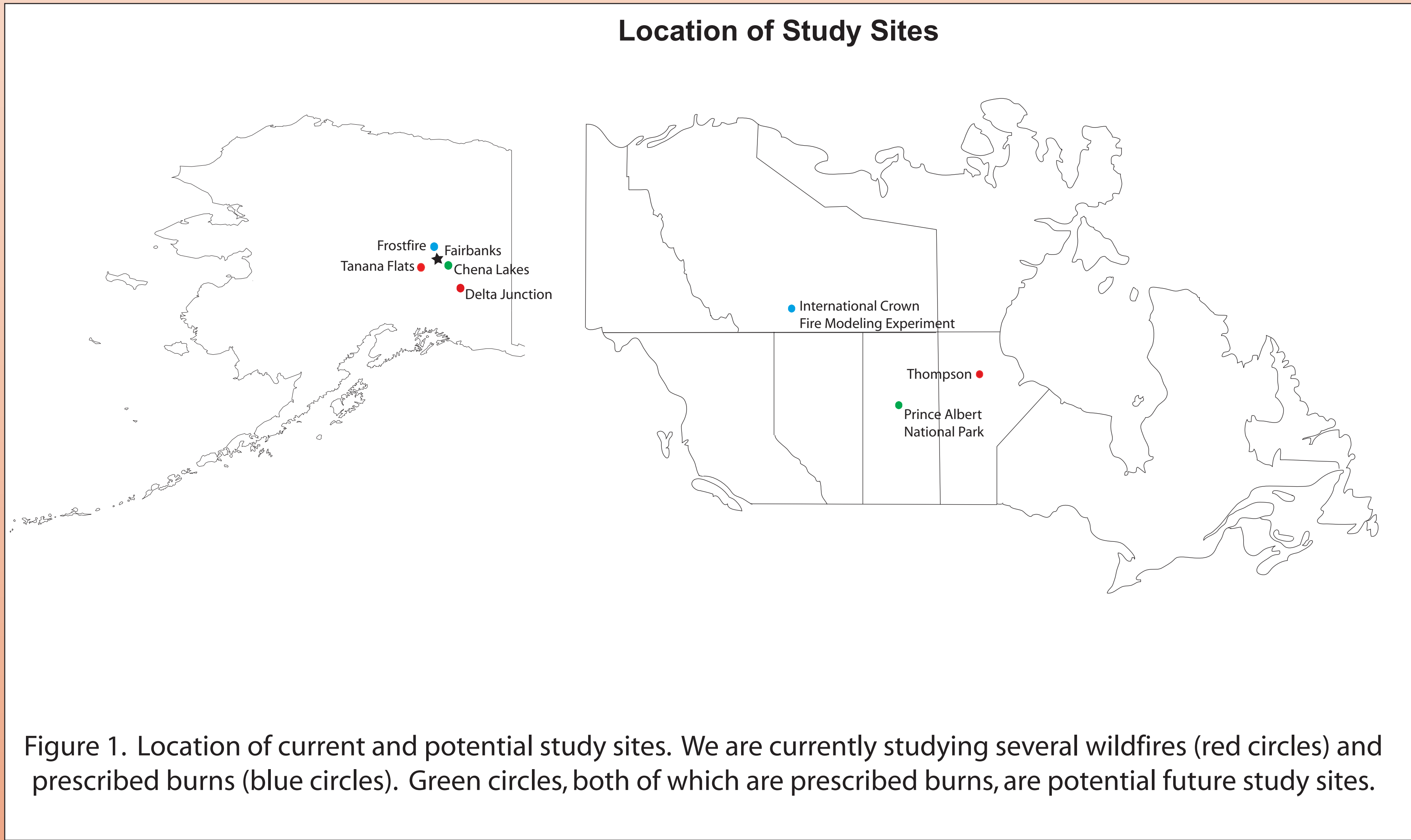
Introduction

Boreal forests, which are strongly influenced by climate change, contain a significant portion of the world's terrestrial carbon in their surface fuels and organic soil horizons. Soil drainage is a major controller of the exchange of this carbon at the landscape scale and is closely associated with (1) decomposition rates and fuel storage, (2) fire severity, and, in response, (3) rates of permafrost degradation and recovery, and (4) ecosystem recovery. By studying factors such as the carbon (%C), isotopic (^{13}C , ^{14}C), and elemental (e.g., Hg) content of soil inputs (woody debris, moss, soil organic matter) and outputs (e.g., CO_2 and CH_4), we are providing a conceptual and modeling framework for fire disturbance within these forests at a variety of scales. To gain an understanding of the interactions between fire, soil drainage type, and carbon storage within the boreal forests of Alaska and Canada we are measuring the pre- and post-burn thickness, bulk density, and carbon and nitrogen content of the soil organic layer. These data allow us to estimate pre- and post-burn C and N storage, fuel consumption, emission chemistry, and fire severity. Carbon isotopes are also being utilized to improve estimates of fire severity and evaluate effects of fire on the isotopic composition of atmospheric CO_2 . Through these data we hope to provide a better understanding of the impact of fire on carbon storage within the boreal forest, how this impact is influenced by soil drainage class, and how changes in the global climate might effect the carbon cycling within this system.

Site Descriptions

We are currently working within three separate regions of central Alaska (Fig. 1). Our first area of study is located at Frostfire, a prescribed burn north of Fairbanks (65°N, 147°W) that occurred in 1999. Over 2200 acres of varying drainage classes were ignited for this fire. Approximately 900 acres burned, the majority within the well- and moderately well-drained locations of the watershed. Our second region of study is located near Delta Junction (63°N, 145°W). In 1999 a wildland fire burned over 18,000 acres of moderately well- and well-drained soil drainage types. Other sites of varying burn ages are also found within this region, allowing us to study the recovery of carbon storage and other ecosystem components over time. Our last area of study within Alaska is in the Tanana Flats region (64°N, 148°W). In 2001 a wildfire occurred within several poorly-drained areas within this region.

We also have several study sites located within Canada. First, we participated in the International Crown Fire Modeling Experiment (ICFME), located in the Northwest Territories of Canada during the year 2000. The ICFME study site is located ~50 km north of Fort Providence, NWT (61°N, 117°W). For this burn we had two transects located within well- and moderately well-drained areas of the site. We also have an age sequence of burns, located on well- and poorly-drained sites, near Thompson, Manitoba (55°N, 98°W). This chronosequence will allow us to directly compare how ecosystem recovery differs with different drainage regimes.



THE WILDFIRES OF DELTA JUNCTION, AK: DIFFERENCES AMONG DRAINAGE CLASSES

The 1999 wildfire that occurred near Delta Junction, AK provides a good example of how factors such as amount of organic matter and nutrient storage can vary by drainage type. We located sites within both excessively drained and moderately drained soil types (class 2 and 4, respectively; Fig. 6). Areas nearby which did not burn were also located to provide pre-burn estimates. Four to seven plots were sampled, by horizon type, at each of the four sites. We classified organic horizons as live moss, dead moss, fibric (somewhat decomposed), mesic (moderately decomposed), or humic (very decomposed). Up to eighteen additional sites were described, without sampling, to increase our understanding of the spatial variability within each site. Samples were analyzed for bulk density, percent carbon, percent nitrogen, ^{13}C , and ^{15}N . A subset of samples were also analyzed for ^{14}C .

Organic Matter Thickness

The organic matter (OM) above the mineral soil serves as potential ground fuel and increases in thickness as soil drainage becomes progressively wetter. At our Delta Junction sites, we found an average of 10.6 cm of OM at our unburned class 2 site (somewhat excessively drained) versus 20.0 cm of OM at our class 4 (moderately drained) site. Decomposition rates may be slightly lower at these wet sites, but our working hypothesis is that these deeper organic layers are also due to differences in fire severity. In other words, wetter sites have more OM in part because they tend to burn less. Our Delta Junction data is somewhat supportive of this hypothesis: our class 2 site had an average of 3.6 cm of OM remaining (+/- 2.0), while an average of 11.2 cm of OM (+/- 4.0) remained at our class 4 site.

Carbon and Nitrogen Storage

The amount of organic matter (OM) remaining or lost to fire doesn't directly translate into the amount of carbon and nitrogen stored or emitted, due to changes in bulk density and percent carbon/nitrogen within the organic horizon. Because wetter sites contain thicker humic layers, which have higher bulk densities and tend not to burn, these sites contain more pre- and post-fire carbon and nitrogen. The amount of carbon and nitrogen lost to combustion can also be greater at wetter sites, due to more available fuel, although this value varies with fire severity. Data for Delta Junction (Fig. 2) demonstrate that the amount of carbon remaining and combusted is higher for the class 4 (wetter) versus class 2 (drier) site. These unburned, carbon rich layers allow the wetter sites to increase their long-term carbon storage (Fig. 3).

Isotope Data

Carbon isotopes provide an additional tool for examining differences in storage and emissions among drainage types. At the Delta sites, initial pre-burn soils in wet sites are characteristically lower in ^{14}C because the deepest soil layers contain dense, older organic mats that pre-date the radiocarbon bomb-spike (Fig. 4). Consumption of the forest floor during the recent fire event did not penetrate these deep, old soil layers in the wet site. Therefore, the (1) CO_2 of the smoke was enriched in ^{14}C , and (2) remaining post-burn carbon had lower radiocarbon values than in the dry site. Differences in fire severity result in differences in the ^{14}C of both smoke-derived CO_2 and remaining postburn soils. Our next step is to investigate the role of stand age and fire history in ^{14}C of smoke and postburn soils. Isotopes can also be used as an aid in determining fire severity.

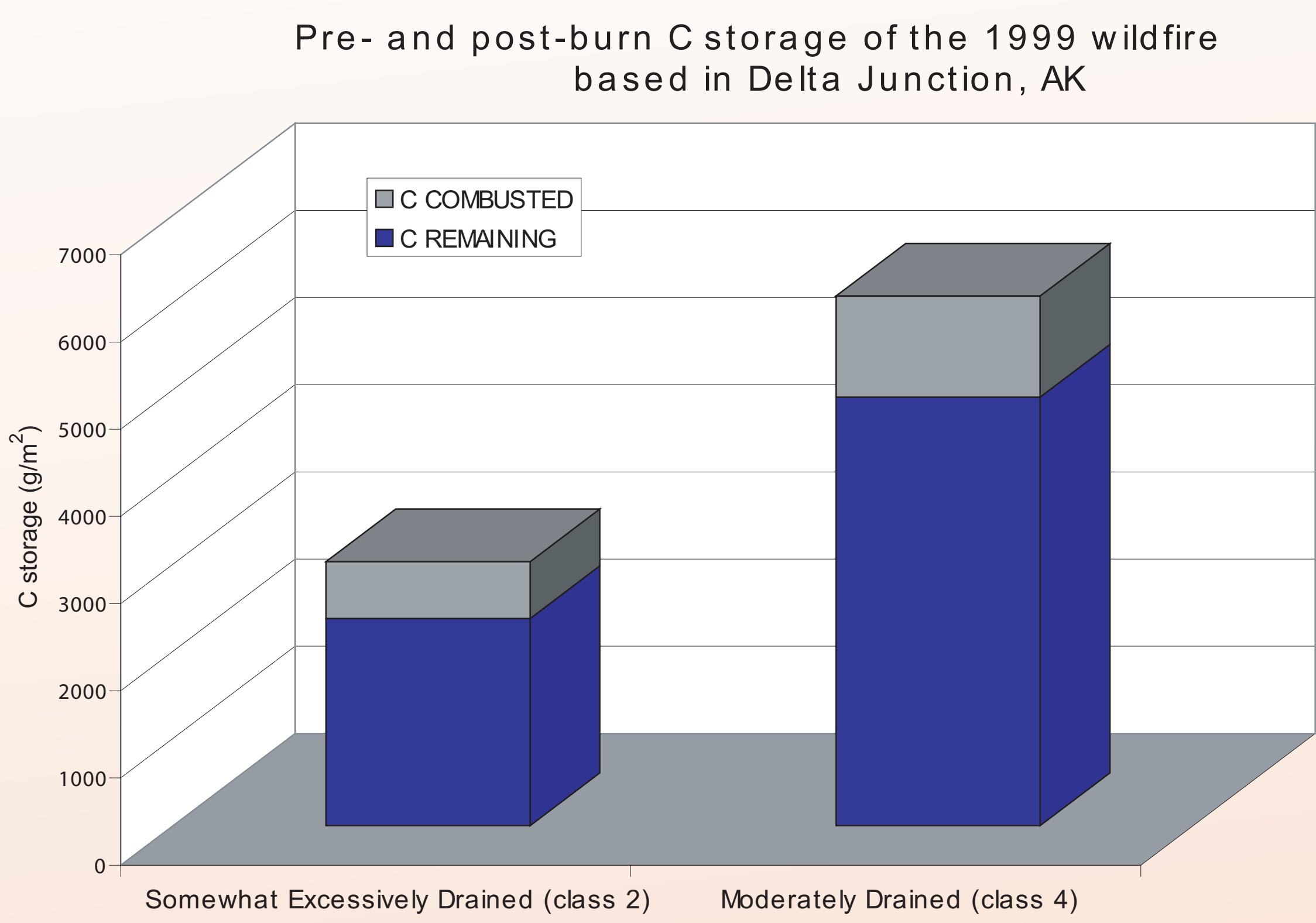


Figure 2. One of our hypotheses is that wetter sites contain more carbon than the drier sites because they burn less often and/or less severely. In this example the wetter site also released more carbon to combustion. Carbon remaining was calculated using data from our postburn site. Amount combusted was determined by subtracting postburn values from what was measured at our control sites.

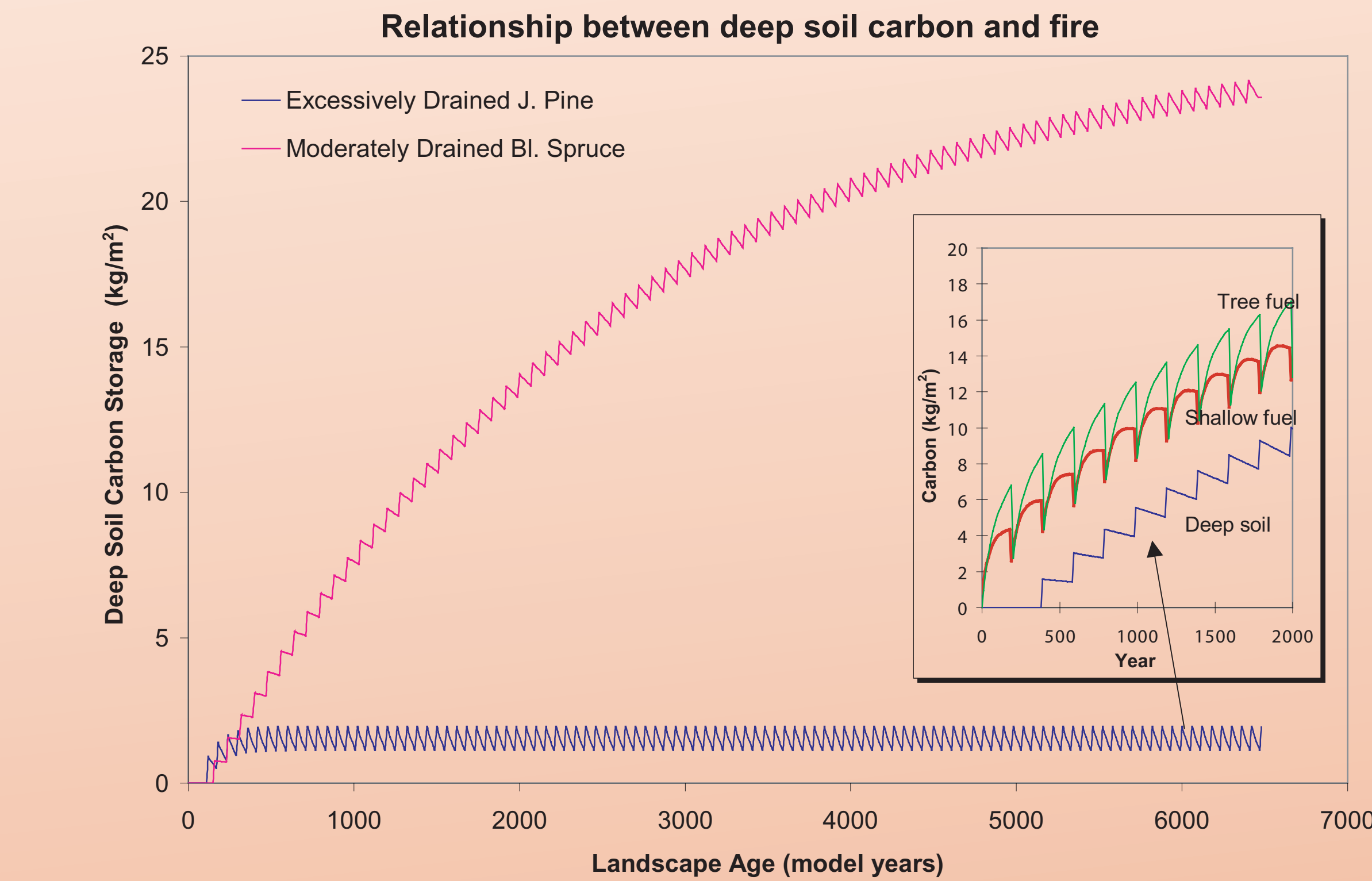


Figure 3. Long-term carbon storage is greater at the wetter site due to larger shallow fuel inputs. Inset: Zigzags represent growth (for fuels) or inputs from unburned shallow fuel (deep soil). Loss is due to fire or decomposition. Data from Thompson, MB, Canada sites. Adapted from Harden et al. (2000).

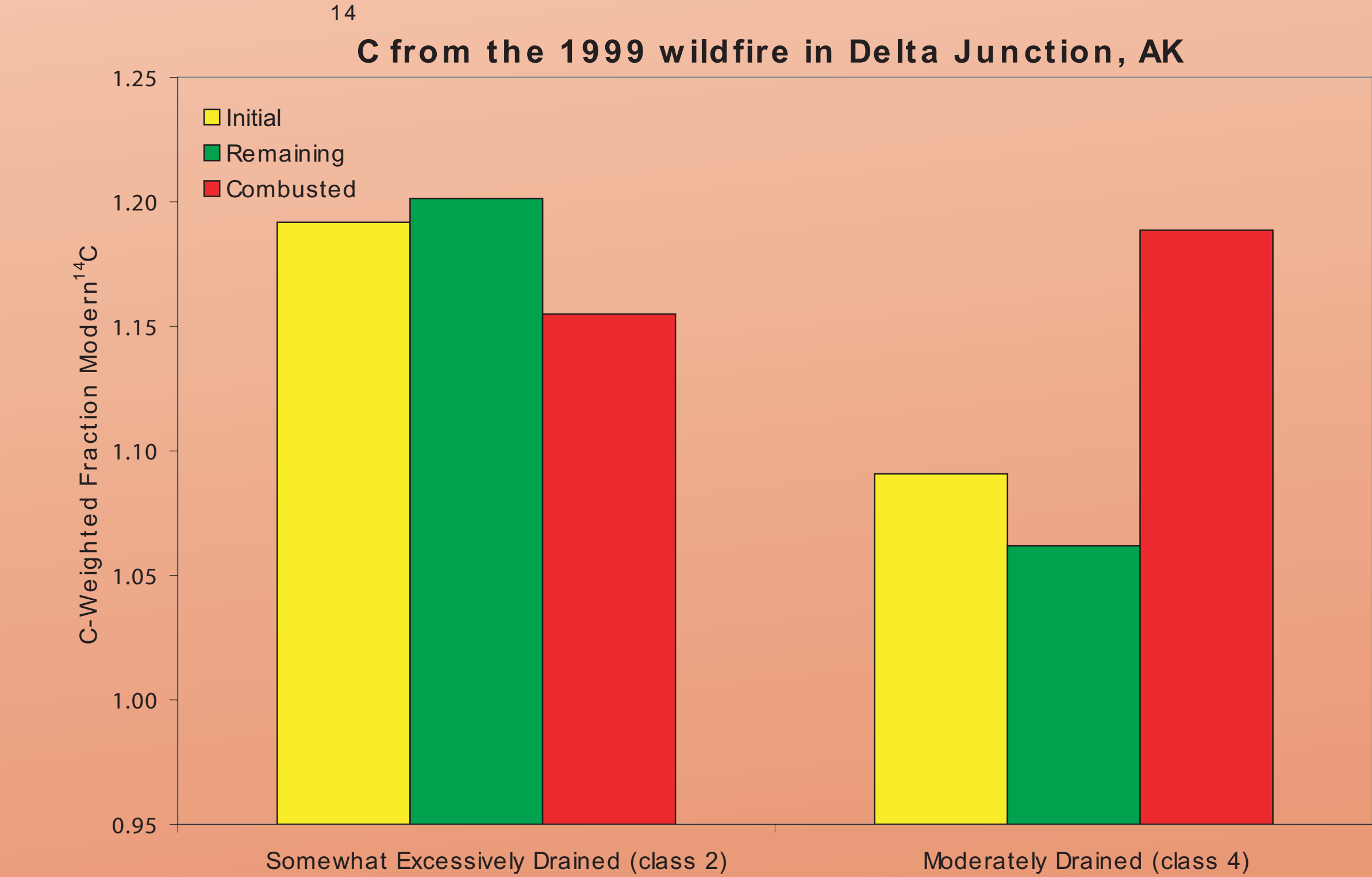


Figure 4. Radiocarbon content of pre-burn soil organic matter, post-burn soil and combusted CO_2 from soil organic matter for somewhat excessively drained (class 2) sites and moderately drained sites (class 4). Radiocarbon content, measured in fraction modern or $^{14}\text{C}/^{12}\text{C}$ units, has been weighted by the carbon density found within the profile.

Consumption

We are also using our data to create element storage relationships and look-up tables that estimate cumulative carbon storage by depth for different drainage types. Fire managers will be able to use these tools to calculate C and N emissions from pre- and post-burn organic matter thickness data. Example curves developed for the Frostfire prescribed burn are shown in Figure 5. We measured an average of 5.5 cm of OM remaining at the well drained (class 3) site post-burn. Therefore, an estimated 1023 g/m² of carbon was lost to emissions.

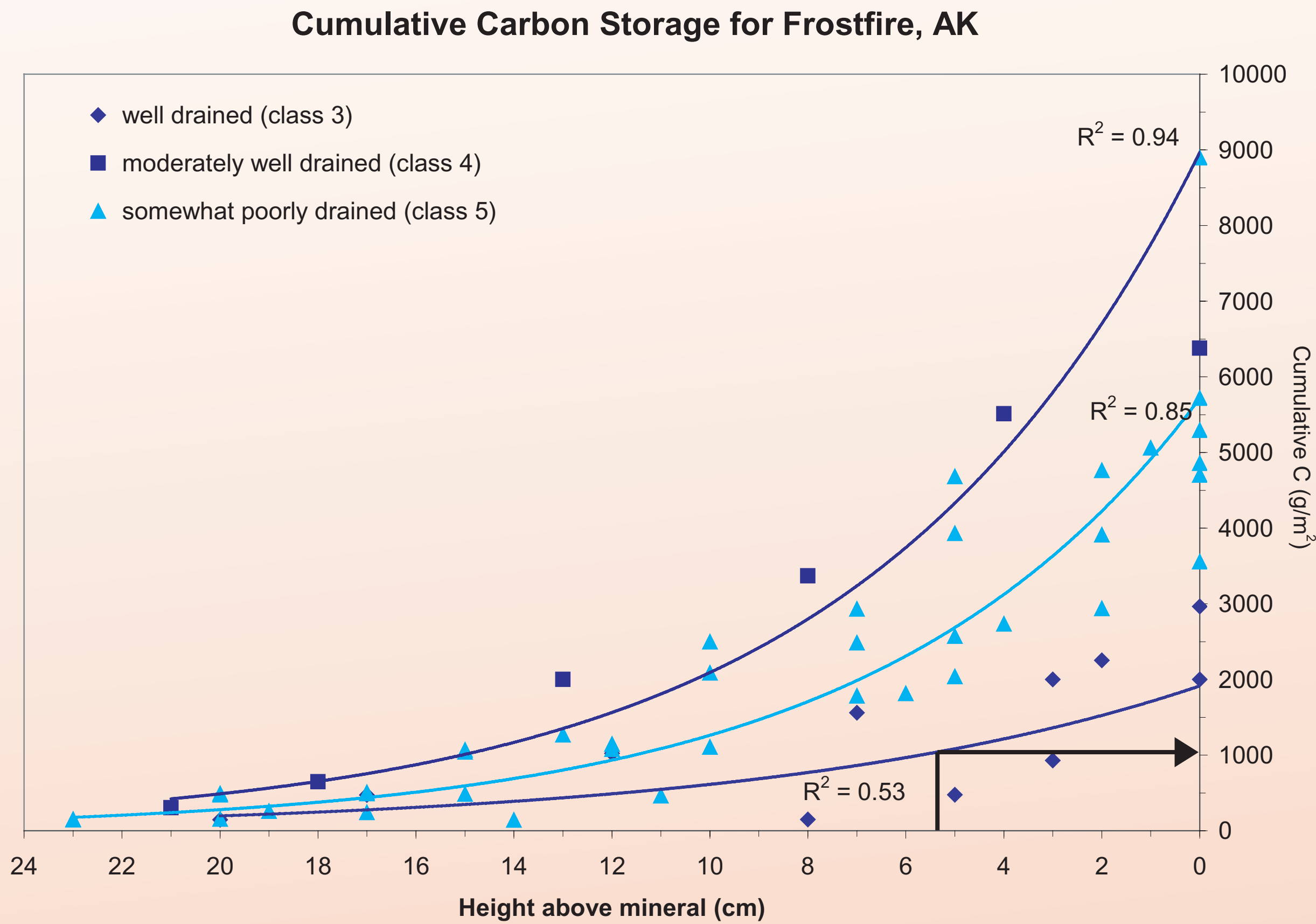


Figure 5. Another method of estimating carbon emission values which we are testing uses carbon accumulation curves based on field data. Post-burn organic matter thickness can then be plugged into these equations to estimate the amount of carbon lost (arrow)

Conclusions

Factors that influence the cycling of carbon, nitrogen, and other elements within the boreal forest include fire severity, fire return intervals, stand age, and soil drainage. Therefore, a strong synergy exists among fire science, carbon-cycle science, forest productivity, and ecosystem health. Data compilation, modeling, and scientific outreach should be tailored to enhance the synergy among these sciences.

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